Neural Activation Patterns Arising From Gesture Recognition

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment of the Requirements for the Degree
Bachelors in the School of Biology

Georgia Institute of Technology
December 2015

Neural Activation Patterns Arising From Gesture Recognition

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Date Approved: December 11, 2015

To Amma (Mom) & Abba (Dad), the pillars on which I stand.

ACKNOWLEDGEMENTS

A special thank you to my faculty mentor Dr. Lewis Wheaton for inspiring in me a passion for neuroscience and my graduate mentor Dr. Nikhilesh Natraj for guiding me throughout my research experience in the Cognitive Motor Lab. Thank you to the Undergraduate Research Opportunities Program for facilitating my undergraduate research endeavors and providing me the opportunity to present at the Neuroscience 2015 conference through PURA funding.

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NOMENCLATURE: LIST OF SYMBOLS AND ABBREVIATIONS

fMRI	Functional Magnetic Resonance Imaging
FSL	Linux Based fMRI Analysis Software Library
GLM	General Linear Model
Abbrev2	What it Means

ABSTRACT

The human brain is composed of a complex network of neurons that create a representation of the world through sensation and perception. This representation facilitates interacting with the environment and is thus vital to the human experience. One aspect that is crucial to normal functioning is the ability to identify and classify the different types of gestures we see every day. Broadly, gestures are classified into three categories: transitive, intransitive and neutral. Transitive gestures involve specific hand-object actions such as tool-use; while, intransitive gestures are communicative in nature. In this experiment, we propose that the main aspect of a gesture is the context in which the gesture is performed. For example, the gesture of waving goodbye to someone, an intransitive gesture, and the gesture of wiping a window, a transitive gesture, both involve the same biomechanics and motor control; however, they differ greatly based on the context in which they were performed. To understand and differentiate such kinematically similar gestures, the cerebral cortex or deep brain structures might exhibit unique patterns of activations specific to differentiating context. Therefore, the objective in this experiment is to map patterns of neural activation that specifically encode and differentiate context when viewing kinematically similar transitive and intransitive gestures. The participants recruited were 19 young adults between the ages 20 to 30. To map the pattern of neural activation, this experiment employed the use of a neuroimaging technique called functional magnetic resonance imaging or fMRI. fMRI indirectly measures the hemodynamic response that represents the flow of blood to specific regions of the brain that are active in response to the viewing a picture such as a particular type of gesture. Each participant was placed in an MRI machine and exposed to 75 images

containing gestures in either a transitive, intransitive, or neutral context. For the purposes of this experiment, we defined the neutral context as a gesture devoid of any context. Once the data was collected, a Linux based software called FSL was used to analyze the data. Analysis thus far has displayed neural activation patterns for the three types of gestures primarily in the visual cortex, along the dorsal and ventral streams and along the primary motor cortex. When contrasting transitive and intransitive gestures, there is no difference in neural activation. Data from this experiment gives insight into the basic neuroscience of how the brain effortlessly recognizes daily gestures and has clinical implications towards ideomotor apraxia, a neurological disorder that is characterized by an inability to recognize and perform transitive gestures.

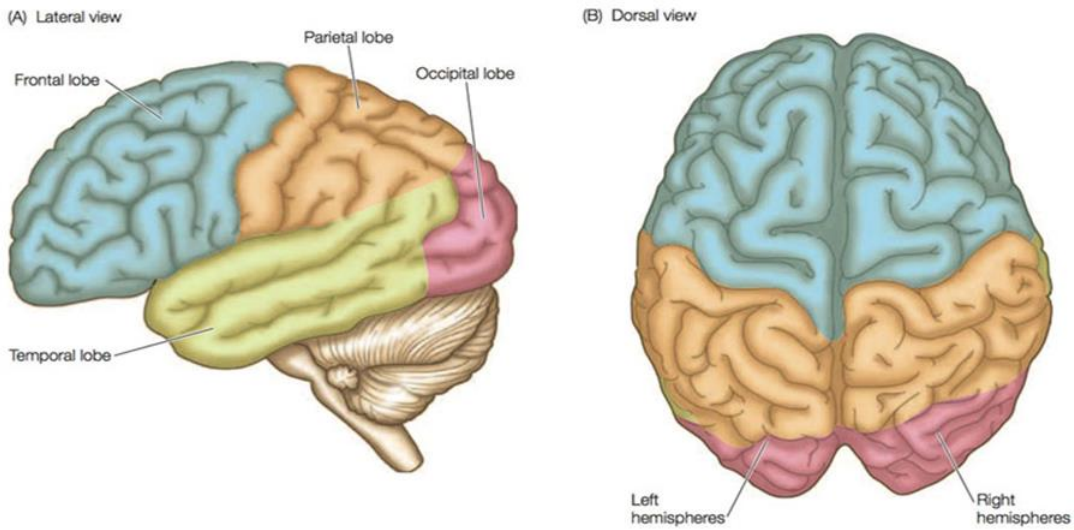


FIGURE 0.1: Cerebral Cortical Structure

The color contrasted image above differentiates the four major lobes of the cerebral cortex: the frontal lobe, the parietal lobe, the temporal lobe and the occipital lobe. Each of the lobes integrate a stream of sensory information which facilitates an understanding and an interpretation of the environment. The various folds are created by the corresponding gyri (ridges) and sulci (grooves) within the cerebral cortex.

CHAPTER 1

INTRODUCTION

The human brain is composed of a complex network of neurons that create a representation of the world through sensation and perception. The representation created must provide the ability to identify specific aspects of the human experience. One aspect that is crucial to normal functioning is the ability to identify gestures in a specific context. The importance of identifying gestures can been seen in patients that suffer from apraxia, specifically ideomotor apraxia, which is most likely to occur in patients who have recently been afflicted by a stroke or are suffering from a neurodegenerative disorder.[5,6] Ideomotor apraxia is defined as the inability to perform purposeful movements such as gestures.[5] Gestures are classified into three categories: transitive, intransitive and neutral.[1] Transitive gestures are tool based gestures; while, intransitive gestures are communicative gestures.[2] Neutral gestures are neither transitive nor intransitive. Prior studies suggest that these gestures displayed varying levels of neural activation patterns in the sensorimotor cortices, temporal cortex, posterior partial cortex, and the visual cortex.[1] Focusing particularly on transitive gesture recognition, research has mapped the processing of transitive gestures based on the dorsal stream pathway, beginning in the primary visual cortex and moving towards areas within the partial cortex and motor cortex.[2] Focusing particularly on intransitive gestures, neural activation occurred in the left inferior frontal gyrus in addition to the usual areas of neural activation.[1] Activation in the left inferior frontal gyrus is interesting because of its proximity to Broca's area for speech suggesting a co-localization of speech and speech related gestures.[1,8] The method often used by researchers to map neural activation patterns include the fMRI and GLM analysis which often provide accurate results when a base level of assumption is made.[10] Current research has focused on mapping activation patterns for gestures; however, the main aspect of a gesture is the context in which the gesture is performed. For example, the gesture of waving, an intransitive gesture, and the gesture of wiping a window, a transitive gesture, both involve the similar motor output; however, they differ greatly in the context in which they were performed. Classically, the assessment of apraxia may involve recognition of pantomime of these gestures, which may be problematic as pantomime removes action context. However, context may be critical in driving action recognition to derive action intent. The basis of this experiment is derived from the mirror neuron system which is integral to gesture recognition.[14] The objective in this experiment is to map the pattern of neural activation for each type of gesture in a specific context. Focusing on both transitive and intransitive gestures, this experiment hopes to find the only the neural activation patterns that code for context of each type of gesture. Since the research currently being conducted gives insight into the pathways of gesture recognition and neural activations associated with decoding context, this will improve the likelihood of a better diagnosis of Ideomotor Apraxia, which is often misdiagnosed.[5] An increase in the knowledge of gesture recognition and role of context will also pave the way forward towards better rehabilitation and therapy techniques, strengthening the connection between physiology and pathophyisology.[5]

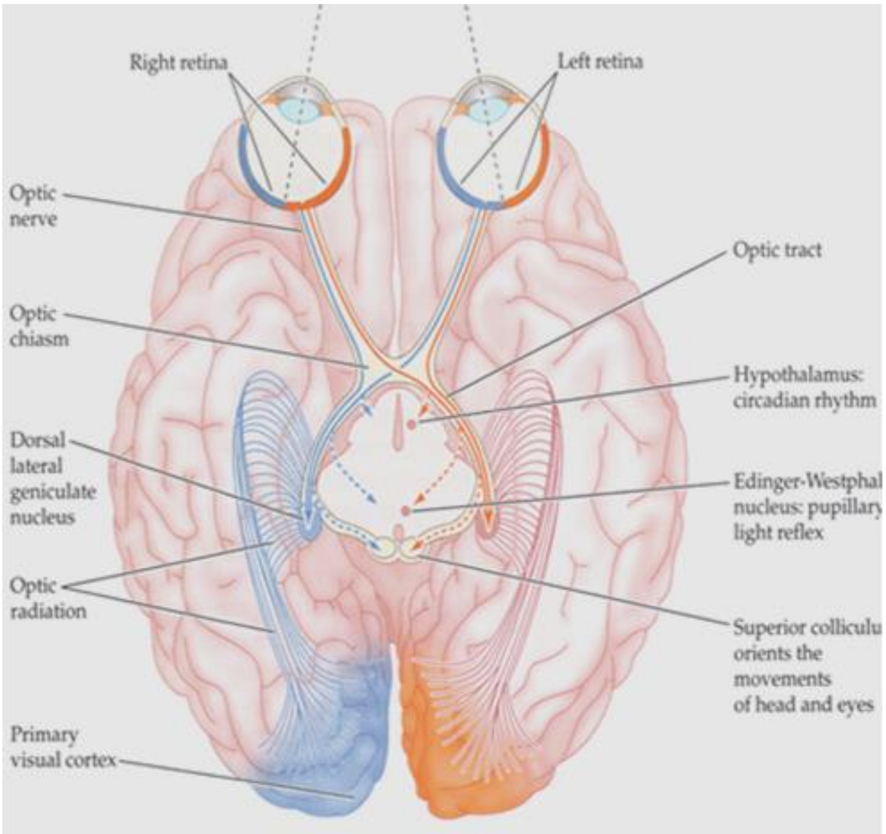


FIGURE 1.1: Pathway of Visual Information

When visual information such as gestures enters your visual field, light is converted into electrical signals within the retina via a process of sensory transduction. Visuals information flows from the retina and decussates at the optic chiasm. Visual information then travels to the thalamus, the primary relay of sensory information. Via optic radiation, visual information travels from the thalamus to the primary visual cortex. The decussation of visual information is responsible for the contralateral processing of visual information by the primary visual cortex.

CHAPTER 2

BACKGROUND

The brain's ability to recognize gestures is crucial not only to normal functioning, but also to the overall human experience. Prior research has focused on mapping the general pathways of gesture recognition. For example, research has shown that all types of gestures displayed cortical activation in the pre-supplementary motor cortex, temporal cortex, posterior partial cortex, and the visual cortex.[1] Prior research also focused on mapping the general pathways for recognition for each type of gesture. Gestures are classified into two categories: transitive and intransitive.[1] Transitive gestures are tool-based gestures; while, intransitive gestures are communicative gestures.[2] Focusing on transitive gestures, research has mapped the processing and activation of transitive gestures in light of the dorsal stream beginning in the primary visual cortex and moving towards areas within the partial cortex and motor cortex.[2] Focusing on intransitive gestures, research has found activation in the left inferior frontal gyrus in addition to the major areas of activation present in both types of gestures.[1] Since prior research has primarily focused on creating general maps of neural activation patterns for gesture recognition to the pantomimed gestures, the goal of this experiment is to extrapolate the specific activation patterns to understand how context can differentiate motor acts that are similar if they were pantomimed. This experiment proposes that when the kinematics of an action are similar, context defines whether the action is transitive or intransitive.

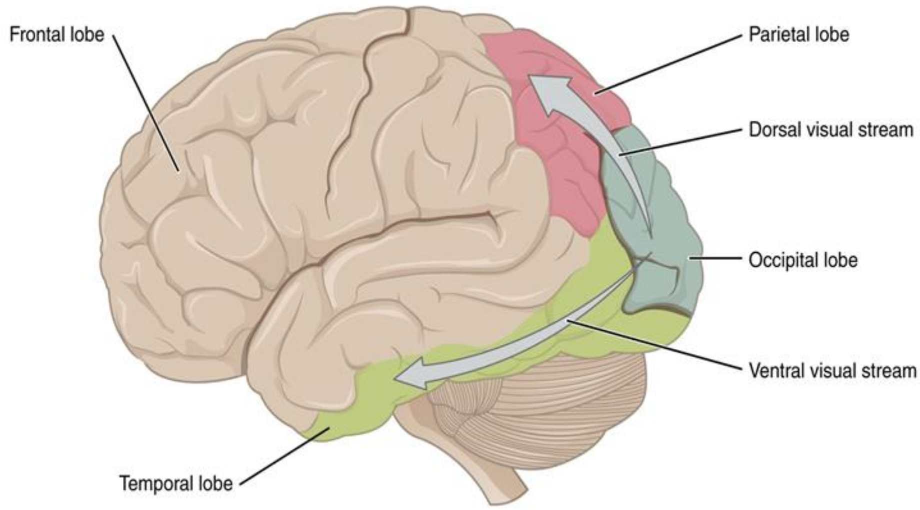


FIGURE 2.1: Streams of Visual Information

After visual information such as gestures is processed in the primary visual cortex, it follows two streams: dorsal stream toward the parietal cortex and ventral stream towards the temporal cortex. The ventral stream functions to conceptualize and recognize of object; while, the dorsal stream functions to decipher the properties of the object such as size, shape and location.[15]

Neural Activation Imaging Device

Multiple methods of creating maps of neural activation exist within the field of neuroscience. Primarily experiments use two methods: electroencephalogram, EEG, or functional magnetic resonance imaging, fMRI. Using electrodes placed on the scalp of a participant, EEG monitors the electrical activity of the participant while completing a task. EEGs are a useful tool to study regions of gray matter on the cortex near the skull of the brain.[3, 4] Since most regions used in gesture recognition are on the cortex, EEG is an effective method for collecting the neural data as seen by multiple experiments using

EEG to study gesture recognition.[5] However, EEGs is not very useful for gray matter sub-cortical structures such as basal ganglia which may also be affected because the EEG electorades are placed on the participant's scalp far from sub-cortical regions. Therefore, the fMRI is a more effective tool to creating a complete map of potential cortical and deep brain activations patterns arising from gesture recognition. The fMRI indirectly measures the hemodynamic response which represents the blood flow to certain area of the brain or the BOLD response via the use of a magnetic field, radiofrequency coils, and gradient coils. Radiofrequency coils are used to emit the initial radio signal and gradient coils are used to pinpoint the signal spatially.[13] Recent experiments and this experiment uses fMRI to derive a complete neural activation map with both cortical and sub-cortical regions.[1, 2]

Image Presentation Design

Once the participant is in the fMRI scanner, the participant views a series of images. The series of images are presented in forms: a mixed block and event-related design. A recent experiment has utilized block image design to create neural activation maps.[6] However, event-related images are more effective than block images because event-related images provide a barrier against repetition suppression. Repetition suppression is an attenuation of neural activation and occurs when a stimulus repetition is expected.[7] Repetition suppression can be caused by sensory neuron fatigue due to repeated stimulus exposure or by sensory neuron efficiency pinpointing only the areas of neuron recruitment needed. [7] To avoid the inaccuracy of data collection due to repetition suppression, this experiment proposes a mixed design of event-related images and block images arranged in sequential on-off design.

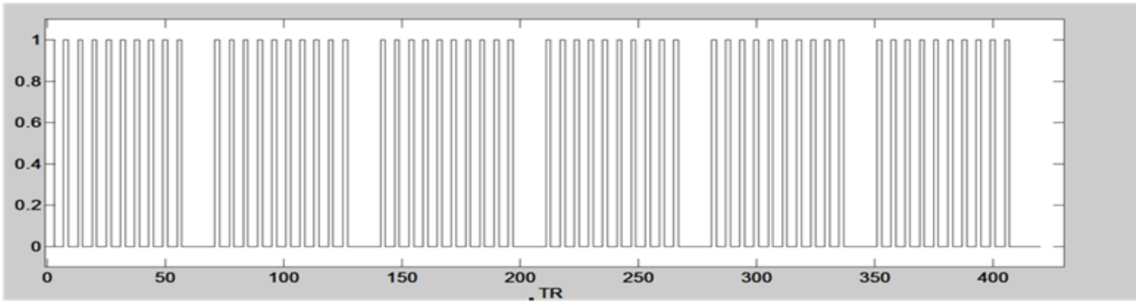


FIGURE 2.2: Image Presentation Design

The graph above represents a series of images in the form of bars presented in a mixed blocked and event-related design. Each image displayed is separated by the fixation cross correlating to event-related design. Also, a group of images create a block and those blocks in turn are separated by another fixation cross correlating with block design.

Choice of Analysis Method

Once the data from the fMRI is compiled, a plethora of methods for data analysis exist within the field of neuroscience. Common methods include Partial Least Squares analysis (PLS) analysis and FSL analysis. PLS analysis is a multivariate approach to analyzing whole-brain activation.[8] PLS analysis is used to find the relations between the covariance of data.[9] On the other hand, FSL analysis analyzes the entirety of the data by dividing it into a lower level and a higher level. Lower level analysis using FSL includes brain extraction from the skull, brain reorientation, motion correction, general linear model integration and brain registration. The general linear model (GLM) utilizes linear regression, the Gaussian distribution, and a design matrix to analyze variance or co-variance within data. [10]Brain image registration entails geometrically adjusting the data derived from the fMRI to fit a certain coordinate system such as standard space.[11, 12] Higher level analysis involves major contrasts and minor contrasts of the data using Bayesian statistics.[9] Both FSL and PLS are useful methods for statistical analysis and power; however, for this particular experiment FSL is a better technique. PLS does not allow for the input and analysis of raw data which is necessary when the data is extrapolated from the fMRI. FSL not only inputs the raw data in lower level analysis, but also generates contrasts in higher level analysis. Also, FSL integrates the hemodynamic response into the interpretation of data.[9] Overall, this experiment utilizes the most effective techniques to derive the most accurate results to support the hypothesis proposed.

CHAPTER 3

Methodology

Participants were composed of 19 healthy, young adults ages 20 to 30. To map the pattern of neural activation, this experiment employed the use of a neuroimaging technique called functional magnetic resonance imaging or fMRI. fMRI indirectly measures the hemodynamic response which represents the blood flow to certain area of the brain or the BOLD response via the use of a magnetic field, radiofrequency coils, and gradient coils. fMRI utilizes the magnetic properties of hydrogen atoms.

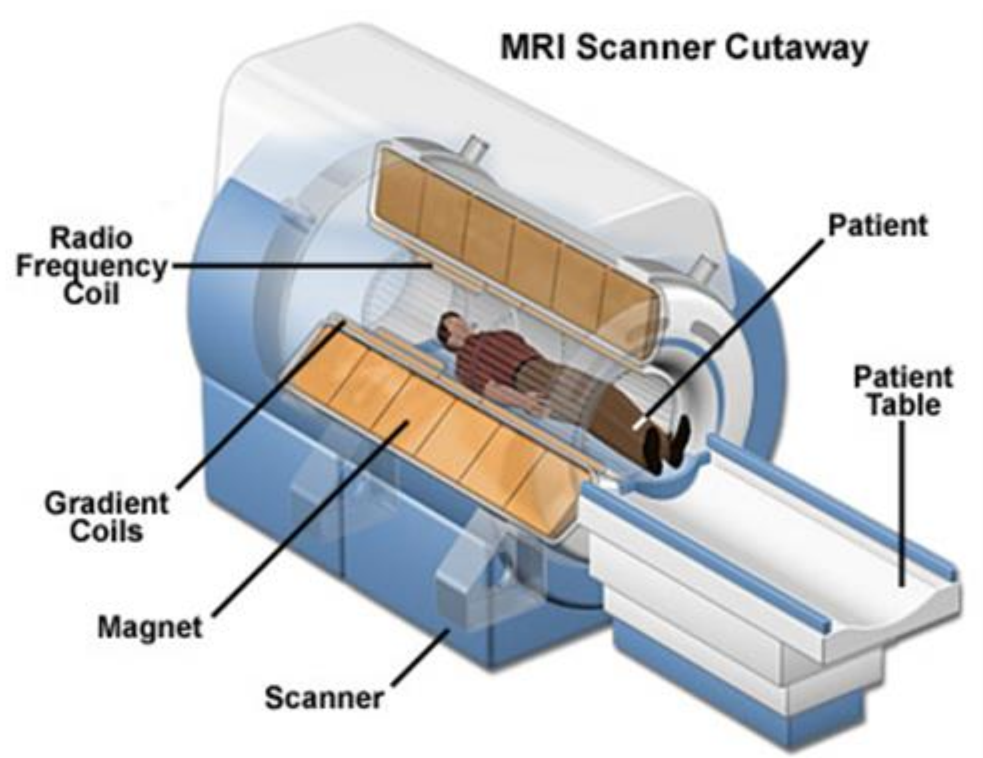


FIGURE 3.1: Functional Magnetic Resonance Imaging (fMRI) Device

The strength of the magnetic field applied is 3 Telsa which is approximately fifty thousand times the Earth's magnetic field. A radio frequency coil sends a signal to the area being imaged; while, the gradient coils oriented in the x, y and z planes allow for spatial localization of the signal.[13] The patient lies supine within the fMRI.

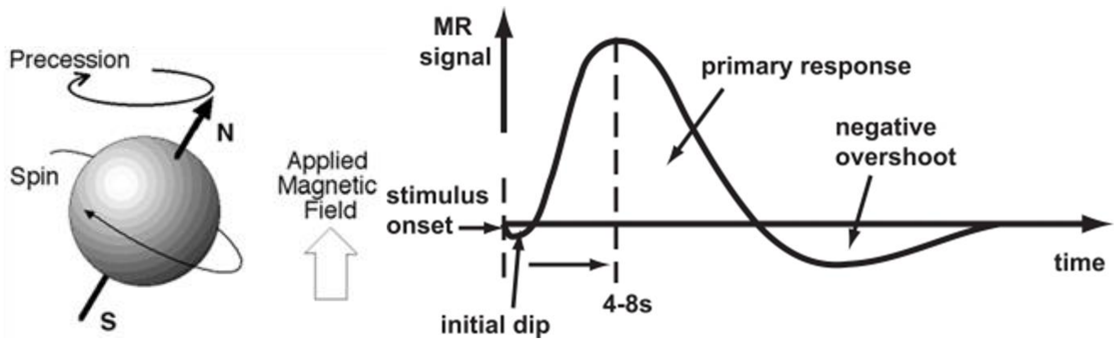


FIGURE 3.2: Functional Magnetic Resonance Imaging (fMRI) Methodology

After a magnetic field is applied, the spins of the protons in the hydrogen atoms produce a magnetic moment that align parallel and anti-parallel to the applied magnetic field, precessing in or out phase in a process referred to as longitudinal magenetization.[16] Gradient coils in the fMRI are arranged in the x,y, and z planes to create small magnetic fields which alter the precession frequencies of the protons allowing for spatial localization of signal.[16] The radiofrequency coils emits a signal to the head area which in turn creates another magnetic field in the opposite direction of the applied magnetic field allowing protons to precess in phase in a process called transverse magnetization.[16] Serve as the collection point for receiving signals, radiofrequency coils are designed for the particular part of the body being imaged allowing for a better signal to noise ratio.[16] These receiving signals are used to create T1 relaxation time image that is parallel to the applied magnetic field (longitudinal) and T2 relaxation time image which is perpendicular to the applied magnetic field (transverse). [16] The receiving signals are processed via an analog to digital conversion into a k-space. [16] Fourier transformation transfers the image from a k-space, digitized fMRI signals, to an actual image of the fMRI scan. [16,17] When looking at an image of the fMRI scan, the cortical and subcortical structures are divided into the 1mm x 1mm x 1 mm cubes of the brain called voxels. Differentiating from basic MRI, fMRI utilizes the blood oxygen level dependency (BOLD) contrast. The BOLD contrast utilizes differences in the magnetic properties of deoxygenated and oxygenated hemoglobin.[17] When neurons in a specific brain region are active, blood flow to that specific region increases in order to replenish the lost nutrients. As blood flow increases, the deoxygenated hemoglobin is replaced by oxygenated hemoglobin. The fMRI utilizes this assumption to indirectly correlate the blow flow with neuronal activity. Once the participant is inside the fMRI machine, each participant was shown a series of images based on a mixed block and event-related design. The series of images were shown in three runs. Run 1 contained all gestures in a meaningless or neutral context. Run 2 was all of same gestures now in a transitive context; while, run 3 was composed of the same gestures now in an intransitive context. As seen in the figure 3.3 below, all gestures were kinematically similar.

FIGURE 3.3: Images of the Three Types of Gestures

The images displayed above present examples of the three types of gestures. Image 1 from the left is an example of a gesture in a meaningless, neutral or ambiguous context. Image 2 located in the middle displays that same gesture in a transitive or tool-based context. Image 3 located farthest right displays that same gesture in an intransitive or communicative context. The Linux-based software called FSL was employed to analyze the data collected from the fMRI. First level analysis using FSL includes brain extraction from the skull, brain reorientation, motion correction, GLM integration and brain registration. GLM or the general linear model utilizes linear regression, the Gaussian distribution, and a design matrix to analyze variance or co-variance within data. [10]

$$y_i = \beta_0 x_{0i} + \beta_1 x_{1i} + \beta_2 x_{2i} + \epsilon_i$$

FIGURE 3.4: General Linear Model

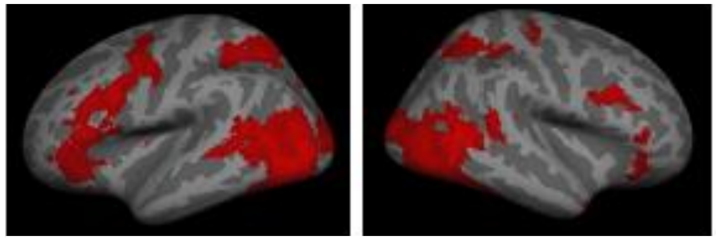
The multiple linear regression equation shown above incorporates the parameters of the experiment through the beta variable, a design matrix through the x variable and error variable with a zero mean Gaussian distribution and lastly, a y variable to encodes modeling of the hemodynamic response. Brain image registration entails geometrically adjusting the data derived from the fMRI to fit a certain coordinate system such as standard space.[11,12] FSL is also used to conduct the higher level analysis; while, FSL View and MRIcron was utilized to create 2D and 3D replicates of the brain. Higher level analysis entails contrasting the varied neural activation responses between the different types of gesture to create differential neural activation maps. Differential neural activation maps provide an avenue to make comparisons between the gestures that provide a means for evaluating significance based 0.05 p value cluster threshold.

CHAPTER 4

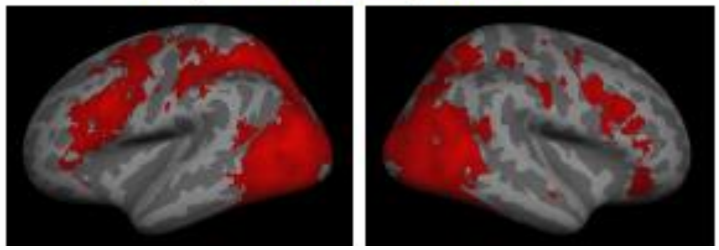
Results

Overall, the neural activation patterns for the three types of gestures display activation primarily in the visual cortex, along the dorsal and ventral streams and along the primary motor cortex. The average neural response for the neutral gestures displays activation in the visual cortex, the posterior parietal cortex, and along the primary motor cortex as seen in figure 4.1. The average neural response for the transitive gestures differentiates from the neutral in its activation along the dorsal stream pathway. The average neural response for the intransitive gestures differentiates from neutral gestures in its activation of both the dorsal and ventral stream pathways seen in figure 4.1.

Neutral Gestures



Transitive Gestures



Intransitive Gestures

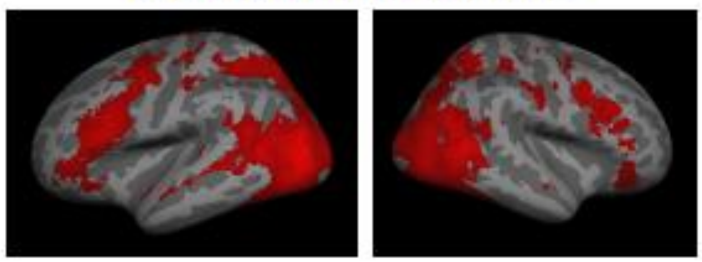


FIGURE 4.1: Average Neural Responses to the Three Types of Gestures

When comparing the differential activation patterns arising from transitive and intransitive gestures, there is no difference in activation as seen in figure 2.

Transitive vs. Intransitive

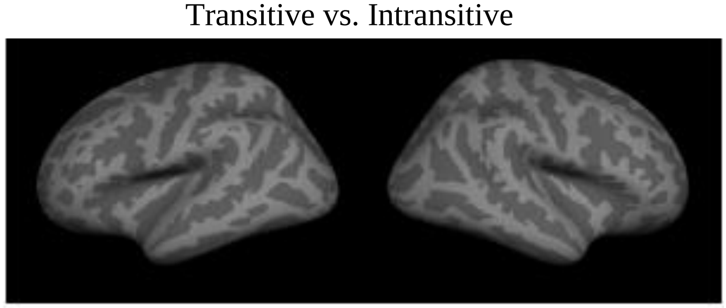
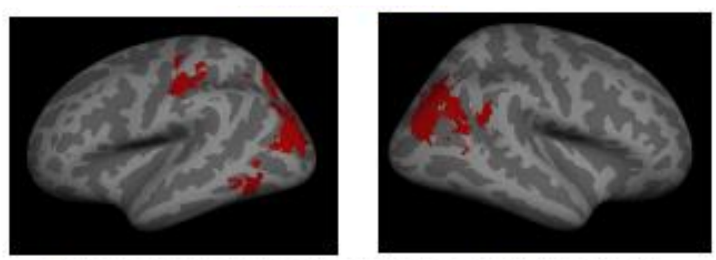


FIGURE 4.2: Differential Neural Activation Patterns Arising from a Comparison of Transitive and Intransitive Gestures

When comparing neutral gestures to transitive gestures, there is significantly greater activation in the bilateral occipital cortex, the left parahippocampal gyrus, the temporal fusiform cortex, the lingual gyrus, the left postcentral gyrus, the supramarginal gyrus, the precuneus, and the right angular gyrus. When comparing neutral gestures to intransitive gestures, there is significant activation bilateral occipital cortex, the occipital fusiform gyrus, the lingual gyrus, the bilateral temporal occipital fusiform gyrus, the supramarginal gyrus, and the bilateral angular gyrus.

Transitive > Neutral



Intransitive > Neutral

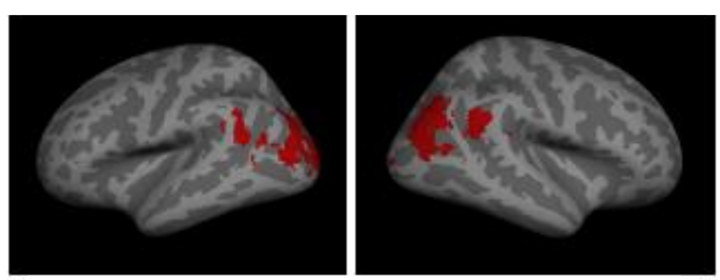


FIGURE 4.3: Differential Neural Activation Patterns Arising From Comparison of Transitive and Intransitive Gestures to Neutral Gestures

CHAPTER 5

Discussion

Results indicate that when comparing transitive, tool-based, gestures and intransitive, communicative gestures, that there is no statistically significant difference between the two types of gestures when encoding for context. Prior research has indicated that a statistically significant difference between the two gestures occurs in IFG or inferior frontal gyrus.[1] The inferior frontal gyrus has been known for inhibition and communication as it contains within it, Broca's Area, essential for speech communication. However, the previous study did not control for the kinematics of the gestures when comparing transitive and intransitive types. Therefore, when controlling for kinematics, even the activation from the IFG disappears implicating that there is no difference in how the brain encodes for context for both types of gestures.

Results indicate when comparing neutral gestures to transitive gestures, there is significantly greater activation in the bilateral occipital cortex, the left parahippocampal gyrus, the temporal fusiform cortex, the lingual gyrus, the left postcentral gyrus, the supramarginal gyrus, the precuneus, and the right angular gyrus. Significant activation is also present in the bilateral occipital cortex, the occipital fusiform gyrus, the lingual gyrus, the bilateral temporal occipital fusiform gyrus, the supramarginal gyrus, and the bilateral angular gyrus, when comparing neutral gestures to intransitive gestures. Neural activation for both transitive and intransitive gestures indicate neural activity beginning in the occipital cortex in accordance to the usual pathway of visual information. The fusiform cortex has been implicated in facial recognition, therefore, it quite interesting that intransitive gestures displayed activation in bilateral temporal occipital fusiform gyrus; while, transitive gesture displayed activation in only the temporal portion of the fusiform cortex.[18] Prior research has developed a connection between lingual gyrus activity and visual attention which is displayed in both types of gestures.[20] Activation in the angular gyrus for both types of gestures is quite fascinating because the angular gyrus has been implicated in memory processing.[21] Therefore, since the angular gyrus is significantly active in both transitive and intransitive gesture when compared to the neutral type, it appears that the two types of gestures evoke memory more than the ambiguous neutral type. Activation in the supramarginal gyrus has been implicated in emotion regulation; therefore, it interesting that the both types of gesture evoke a more emotional response than neutral gestures. Specifically, for transitive gestures, activation in the left parahippocampal gyrus is interesting because the parahippocampal gyrus not only functions as a connection point for memory, but also involved in cognition process that creates contextual association networks.[19] Also, for transitive gestures, activation in the post central gyrus, in the somatosensory cortex, displays the integration nature needed to process transitive gestures over neutral gestures. Overall, these areas of activation can provide the method in which the cerebral cortex and sub cortical structures encode for context because the differentially greater activation occurred when contrasting with neutral, ambiguous gestures with the transitive and intransitive gestures. These areas of activation can aid in our understanding of how the normal brain encodes for context which may provide insight into ideomotor apraxia, strengthening the connection between physiology and pathophysiology.

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VITA

Sumia Basunia

Sumia Basunia’s first experience with research was at the University of Arkansas for Medical Sciences in Little Rock, Arkansas while she was a junior in high school. While working as a junior research student, she discovered her passion for biological research. Pursuing her passion, she joined the Cognitive Motor Lab as an undergraduate researcher.